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Universal computer vision system for monitoring the main parameters of wind turbines

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Abstract. The article presents universal autonomous system of computer vision to monitor the operation of wind turbines. The proposed system allows to estimate the rotational speed and the relative position deviation of the wind turbine. We present a universal method for determining the rotation of wind turbines of various shapes and structures. All obtained data are saved in the database. The presented method was tested at the Territory of Non-traditional Renewable Energy Sources of Ural Federal University Experimental wind turbines is produced by "Scientific and Production Association of automatics named after academician N.A. Semikhatov". Results show the efficiency of the proposed system and the ability to determine main parameters such as the rotational speed, accuracy and quickness of orientation. The proposed solution is to assume that, in most cases a rotating and central parts of the wind turbine can be allocated different color. The color change of wind blade should not affect the system performance.

1 Introduction

Wind turbines have become full-fledged participants in the process of electricity generation. Despite the huge variety, the manufacturers continue their modernization and developing new designs and principles. It is not always possible to evaluate all of testing parameters of new designs or existing wind turbines in different climatic conditions.

Main parameters of the wind turbines are the speed of rotation of the wind wheel, accuracy and quickness of orientation in a fishtail wind. Evaluation of deformation and vibrations of new designs are important characteristics at system calibration and installing.

The recent works show a lot of different ways for determining the parameters of wind turbines [1]. To measure the speed, orientation, vibration and deformations of existing wind wheels it is often necessary to redesign the original installation structure. Such changes require considerable work, change the weight distribution and a starting speed, and may

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affect the quality of the wind generator. Therefore, it is appropriate to develop a system that determines main parameters of wind turbines without changing the design.

One of the promising areas of measuring quantitative characteristics of the wind turbine are the computer vision systems [2, 3]. Such systems are currently being used in the wind turbine stations with pre-defined types of wind generators.

Such systems are difficult to design and are not universal. Determination of the rotational speed in such systems usually occurs by means of edge detection and tracking methods. Such methods do not work well in terms of variability background, lighting, and also it impose restriction: wind generator should be as "propeller-type", it not allowing to work with "screw type" wind turbines.

This article discusses the possibility of applying computer vision application to assess the performance of wind turbines. We focused on creating a simple and universal method for determining the main parameters of the wind turbine.

2 Material and methods

2.1 Experiment

This work is performed at the Territory of Non-traditional Renewable Energy Sources of Ural Federal University.

The installation system consists of several components: multiple cameras, “screw type” wind generator, storage database, and personal computer, which process and analyze data. The scheme of installation system is shown in Figure 1

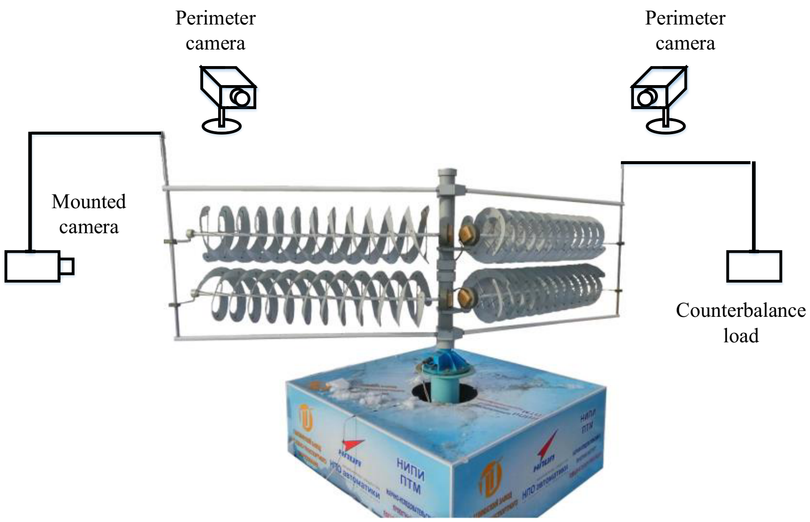

Fig. 1. The scheme of proposed system.

Experimental wind turbines are produced by “Scientific and Production Association of automatics named after academician N.A.Semikhatov”. Each of them consists of two pairs of ‘screw type’ blades, which placed in pairs on the central part of the rotating wind turbine.

The proposed system consists of multiple network video cameras. The cameras allow to capture color frames approximately at 30 frames per second. They were deployed around the perimeter of the wind turbine, and one camera is rigidly fixed to the structure

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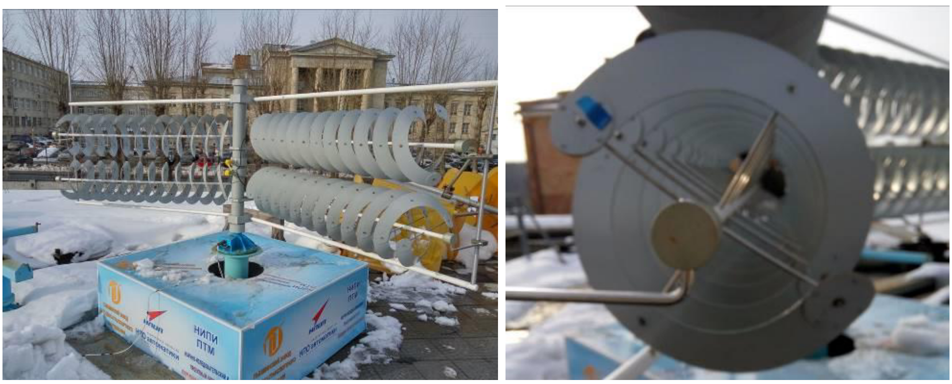
of the generator perpendicular to the axis of rotation. The presence of the camera was balanced on the other side by corresponding load.

The proposed computer vision software is installed on a personal computer that processes data from the camera in real time and transmits the processed data to the storage server [4].

The Figure 2 shows the examples of video images obtained by perimeter and mounted cameras.



a) b)

Fig. 2. The examples of video images obtained by a) perimeter network video camera, b) mounted network video camera attached to the wind turbine.

For evaluation of the wind turbine at the territory of laboratory we have the meteorological station, which allows to observe the speed and direction of the wind, with the ability of accumulation of these data.

2.2 Algorithm

The proposed algorithm is based on the assumptions that the central part and the rotating part of construction of the wind turbine can be allocated by individual colors from the background. It is desirable that the center of rotation and the blade rotation area were different colors.

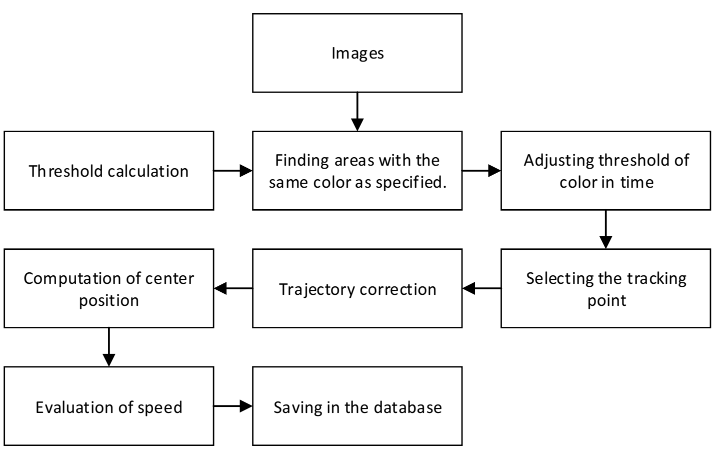


Fig. 3. Block diagram of the proposed algorithm.

The sequence of proposed algorithm:

1. Determination of thresholds for multiple color ranges and formats. Video frames are converted into YCbCr and HSV color formats and HSV to more accurately determine the color used. The YCbCr coordinates are calculated as follows:

$$\begin{aligned} \mathrm{Y} &= 0.299\cdot \mathrm{R} + 0.578\cdot \mathrm{G} + 0.114\cdot \mathrm{B} \\ \mathrm{C_r} &= (\mathrm{R}-\mathrm{Y})\cdot 0.713 + 128 \\ \mathrm{C_b} &= (\mathrm{B}-\mathrm{Y})\cdot 0.564 + 128 \end{aligned} \tag{1}$$

To calculate the HSV coordinates R, G, B are converted to the floating-point format and scaled to fit the 0 to 1 range:

$$\begin{aligned} &V = \max(R,G,B) \\ &\mathrm{S} = \begin{cases} \dfrac{V-\min(R,G,B)}{V}, & if\ V \neq 0 \\ 0, & otherwise \end{cases} \\ &\mathrm{H} = \begin{cases} 60\cdot\dfrac{G-B}{V-\min(R,G,B)}, & if\ V = R \\ 120+60\cdot\dfrac{B-R}{V-\min(R,G,B)}, & if\ V = G \\ 240+60\cdot\dfrac{R-G}{V-\min(R,G,B)}, & if\ V = B \end{cases} \end{aligned} \tag{2}$$

2. Applying the thresholds. After that we use the erode and dilate methods to avoid chromatic noise points.
3. Adjust color thresholds by changes of allocated points chrominance, for tracking in variable lighting conditions.
4. Calculating the position of tracked points [5], by knowing the position and trajectory of previous point. Selection the nearest point with appropriate parameters.
5. The trajectory correction to the circle (for mounted camera) or to the ellipse (for perimeter camera) [6].
6. The center estimation (if it is not allocated).
7. Calculation of speed rotation and other main parameters, by the changes of position of tracked points.
8. Save data to the local database.

The algorithm can also be used for a monochromatic camera. For this it is necessary that the central and rotation points can be excluded from the background. In this case, the definition of the threshold occurs without converting frames to other color formats.

The work of the algorithm depends on the camera capability. According to Nyquist – Shannon sampling theorem camera sampling frequency should be 2 times larger than the frequency of the signal. In our case this means that by using the standard camera with 30 frames per second, we can detect a rotation of 15 rotations per second.

However, it is the maximal rotation speed under ideal condition. In real life condition the actual maximal rotation speed is significantly less, because at high speed the image is blurred and not be able to accurately locate the position of the rotating points. If the actual maximal rotation speed for this system is less than 6 times per second, which is suitable for most wind turbines, since the usual speed (without the storm) does not exceed the threshold.

If the system can not detect the position of a rotation point – it does not calculate a rotational speed and the color thresholding, and waits conditions at which detection is possible.

3 Results and discussion

During the experiment, we check the possibility of assessing main parameters of wind turbine, such as speed, orientation, vibration.

Figure 4 shows changing the wind blade rotation parameters over time: current wind speed and passport starting wind speed. It measured by perimeter cameras from different angles.

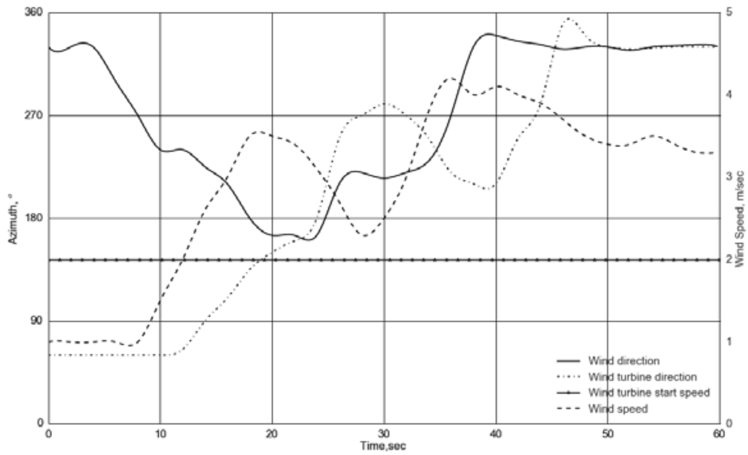


Fig. 4. The registered parameters of wind turbine.

As it can be seen in Figure 4 that mounted camera shows the blade rotation speed more precise, but the perimeter cameras also allow to evaluate the rotation of the wind turbine installation. So, if there is no need for very accurate determination of the blade rotational speed, it is sufficient to use a cameras attached on the perimeter, without making changes in the design of wind turbine.

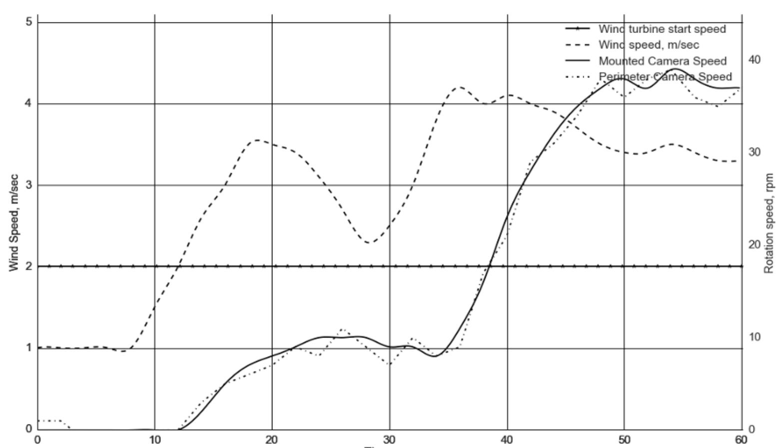


Fig. 5. Position the wind turbine installation, direction and speed of the wind.

To determine these data are sufficient a two standard network video cameras with minimal resolution of 640 x 480 and sampling frequency approximately 30 frames per second. For rapidly rotating generators is necessary to increase the sampling rate of cameras according to the Nyquist – Shannon sampling theorem.

The Figure 5 shows the graphs of the position of the wind turbine blade and wind direction over the time.

The Figure 5 shows that the system can determine the orientation of wind installation in the direction of the wind with sufficient accuracy. It also shows the current and starting wind speed, measured by the weather station. Based on these data it is possible to determine the sensitivity of the wind turbine installation.

4 Conclusion

This article showed that the developed system can detect the rotational speed and position of the wind turbine with sufficient accuracy. The obtained data allow to estimate main parameters of the wind turbine installation and thus allows to callibrate the installation in different conditions without the changes of the design.

The proposed system is a flexible and allows to work with any type of wind turbines with minimal adaptation.

The accuracy of the system depends on parameters of cameras such as image quality and frame rates. Determination of the high-speed rotation with higher accuracy requires more processing power and high speed cameras.

For work at night or in cloudy time, you must provide a lighting installation or, it is possible to use the light or reflective markers instead of the colored marks on the installation.

It is possible to determine variations in the wind turbine, such as vibration and deformation. It will be presented in our further work

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